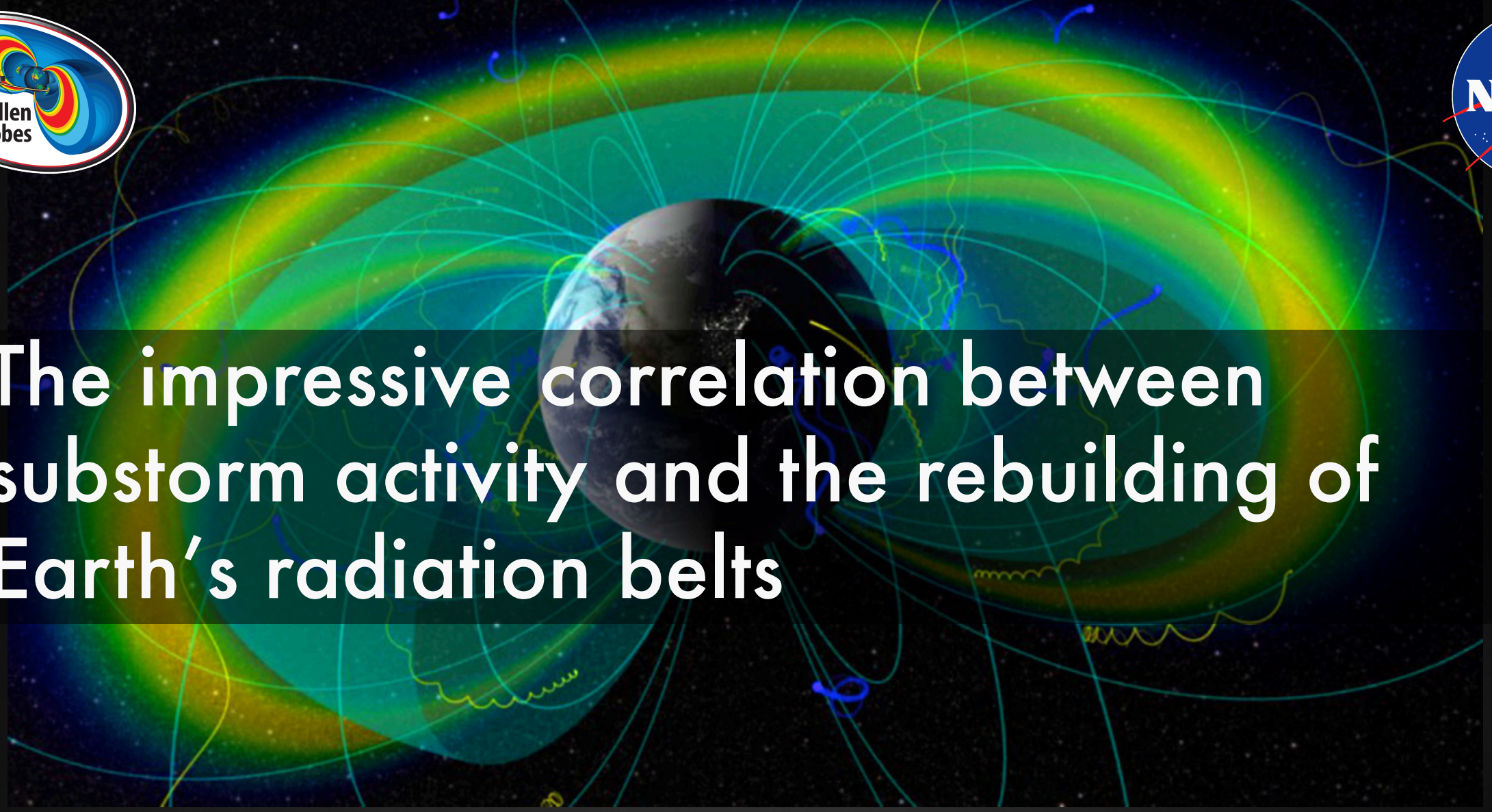

The impressive correlation between substorm activity and the rebuilding of Earth's radiation belts

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The connection between substorms and RBE

- Prolonged substorm activity required [Meredith+ 2002]
- Prolonged southward Bz required [Kataoka+ 2010; X. Li+ 2011; W. Li+ 2015]
- Non-storm times can produce RBE with strong substorms [Schiller+ 2014; Su+ 2014]

Zhao+ 2017

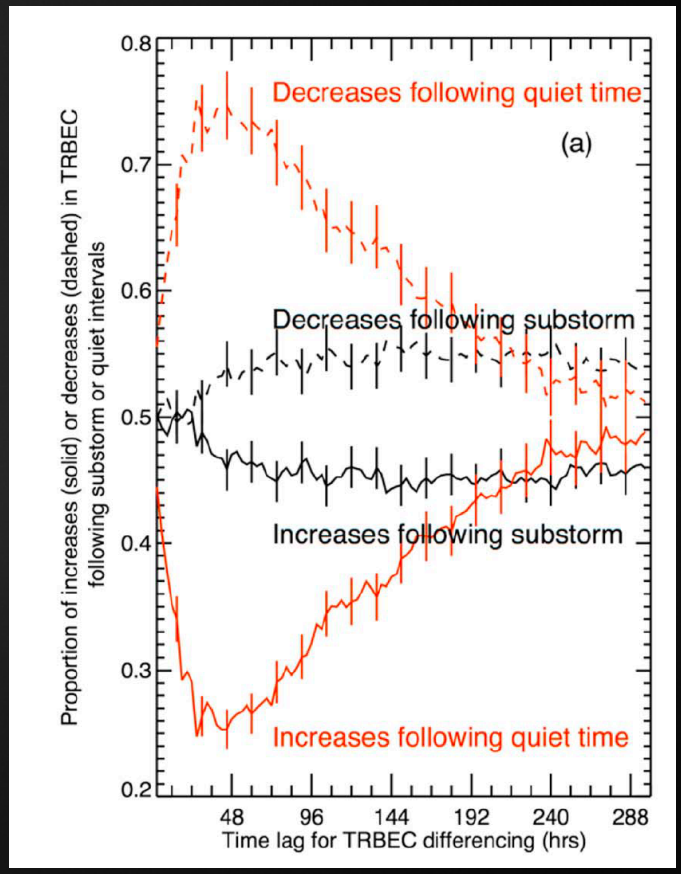
- Correlation coefficient between *AL* index and high-μ electron PSD enhancements can reach almost 0.7 (best correlation among all solar wind/magnetospheric parameters investigated)

Boyd+ 2018

- What Causes Radiation Belt Enhancements: A Survey of the Van Allen Probes Era
- TRBEC (Total radiation belt electron content) – Huang+

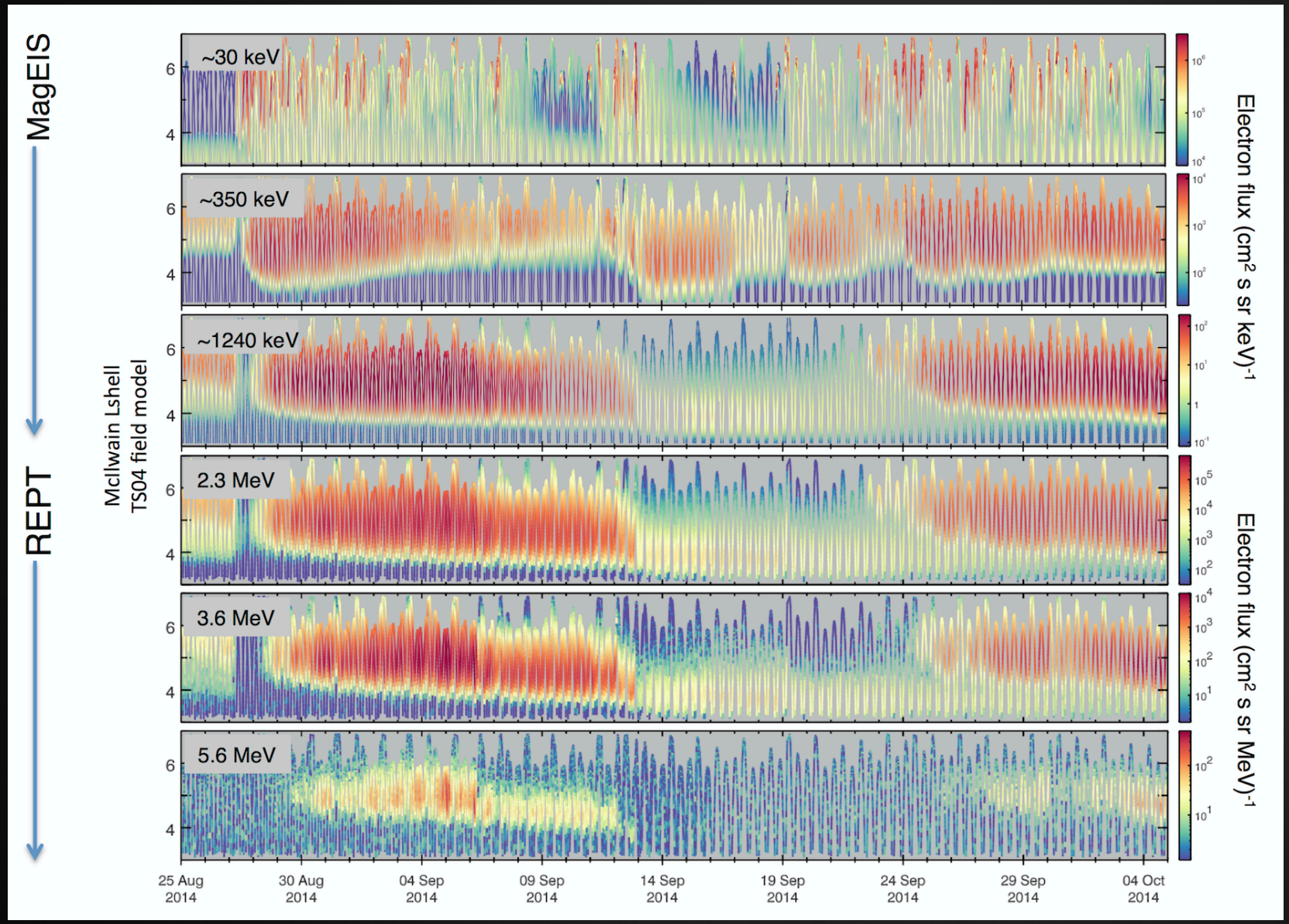
Forsyth+ 2016

- Some substorm intervals result in increases in the radiation belt while others do not
- Effect of substorms is to increase the likelihood of the radiation belts increasing 6 days after their occurrence



The role of source and seed electrons

In September, 2014 a storm period failed to produce high-energy electrons in the radiation belts.



Lack of 10s keV source electrons (due to no substorm activity)

Therefore, no chorus waves

Thus, no acceleration to higher energies

Substorms are crucial to the building of Earth's high-energy radiation belts

Jaynes+ 2015

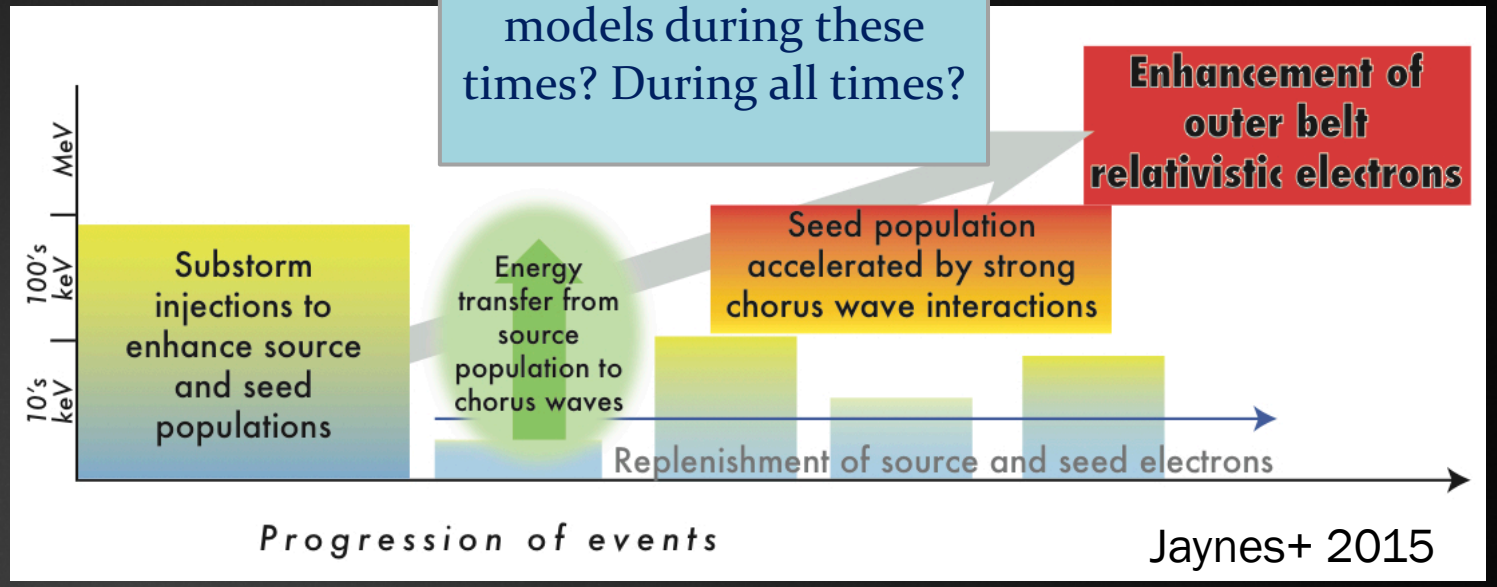
The role of source and seed electrons

Plenty of seed electrons (100s keV electrons that *grow* to higher energies)

No source electrons (few-10s keV that provide the *source* of free energy to waves)

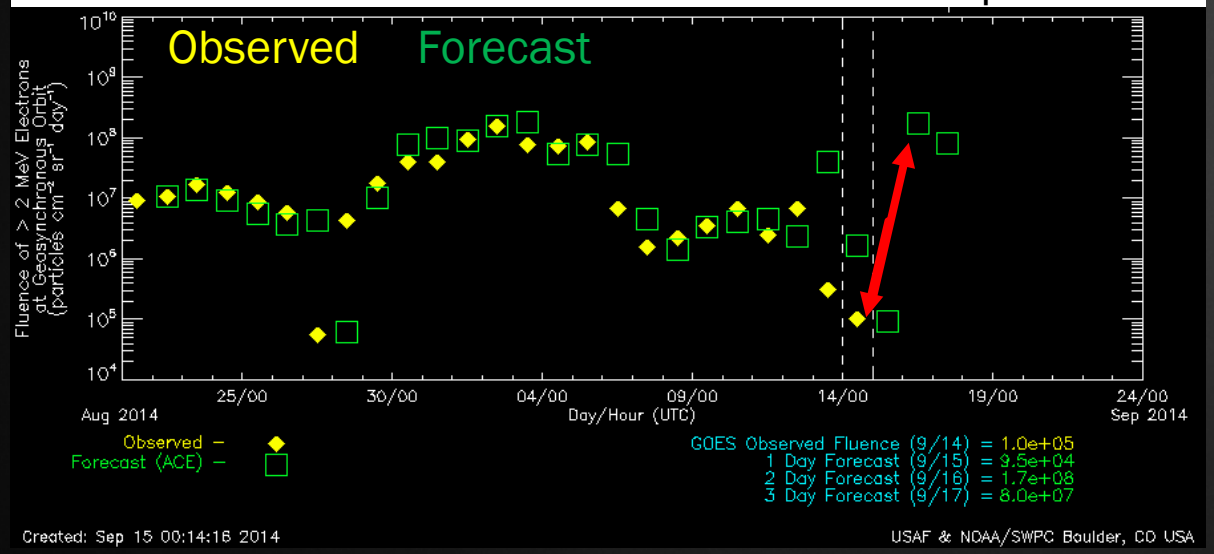
Forecast models continually failed during the first few days of the storm

Can we inform the models during these times? During all times?

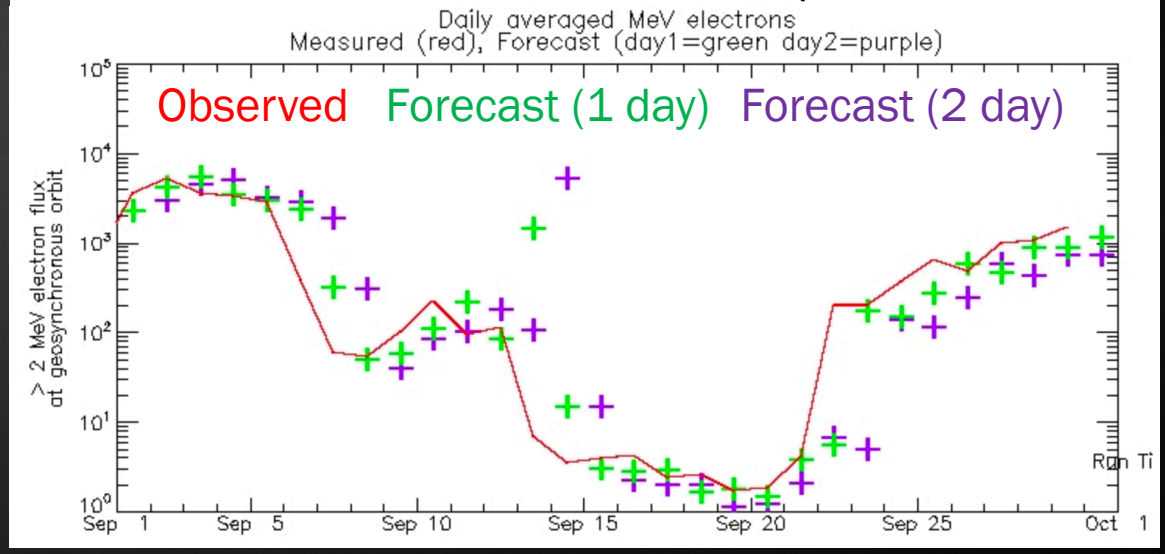


Jaynes+ 2015

Relativistic Electron Forecast Model – 15 Sep 2014

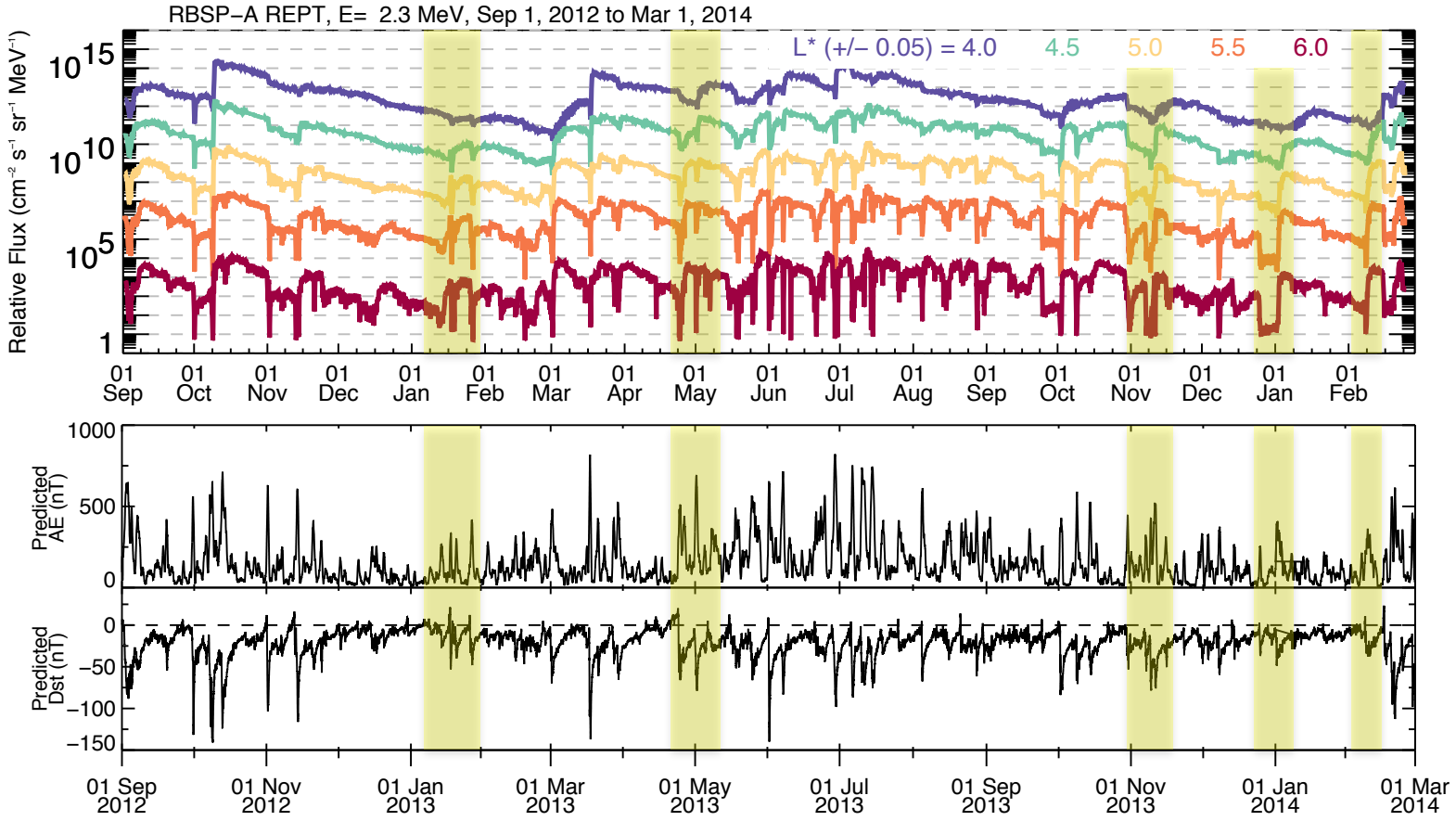


Xinlin's Forecast Model – Sep 2014



AE and >MeV electron flux enhancements: by eye

Long-term flux variations at different Lshell values plotted as flux vs. time where color indicated L value



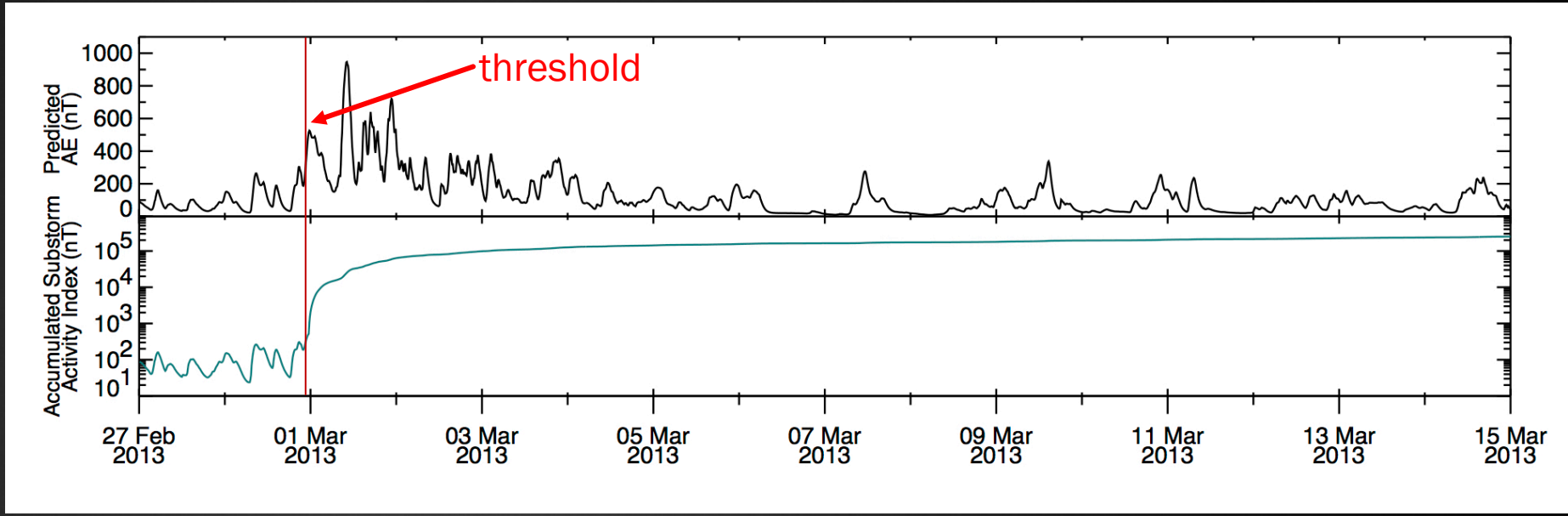
- A number of dropouts as well as enhancements can be seen, dependent on Lshell
- Some enhancements come along with large Dst excursions
- Some enhancements occur during small Dst times, or non-storm time events [e.g. Schiller+ 2014]
- By visual inspection, electron enhancements correspond to periods of intense or sustained AE activity

New index: Accumulated Substorm Activity

Started as an REU student project

Using AE or AL as input, create a new index that takes into account cumulative effects of sustained substorm activity

A certain threshold in AE value must be reached before the accumulation is triggered



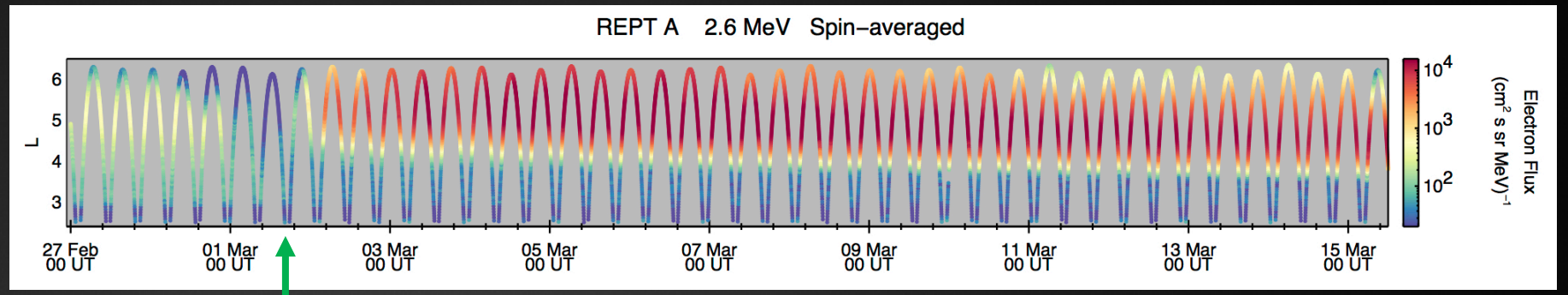
Once this threshold is reached, the Accumulated Substorm Activity (ASA) index is computed as a cumulative sum:

$$ASA_n = \sum_{i=0}^{n} AE_i$$

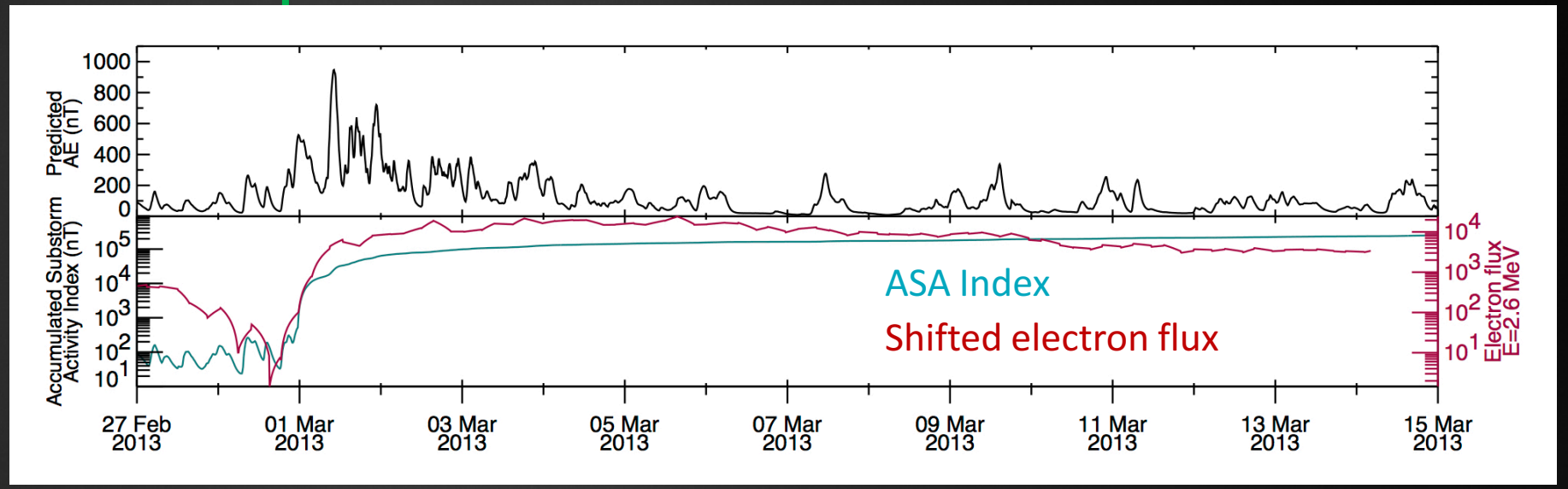
ASA does not include any terms for electron lifetime and thus decay of flux, or electron dropouts. It can only describe the enhancements during a time of heightened substorm activity.

Case study I: March 01, 2013 small storm

Small storm occurred on March 01, 2013 – entirely distinct from the March 17, 2013 infamous storm two weeks later



ASA index was calculated and plotted with 2.6 MeV electron flux (shifted to find best correlation)



Correlation coefficients and lag times

Lag time increases with energy

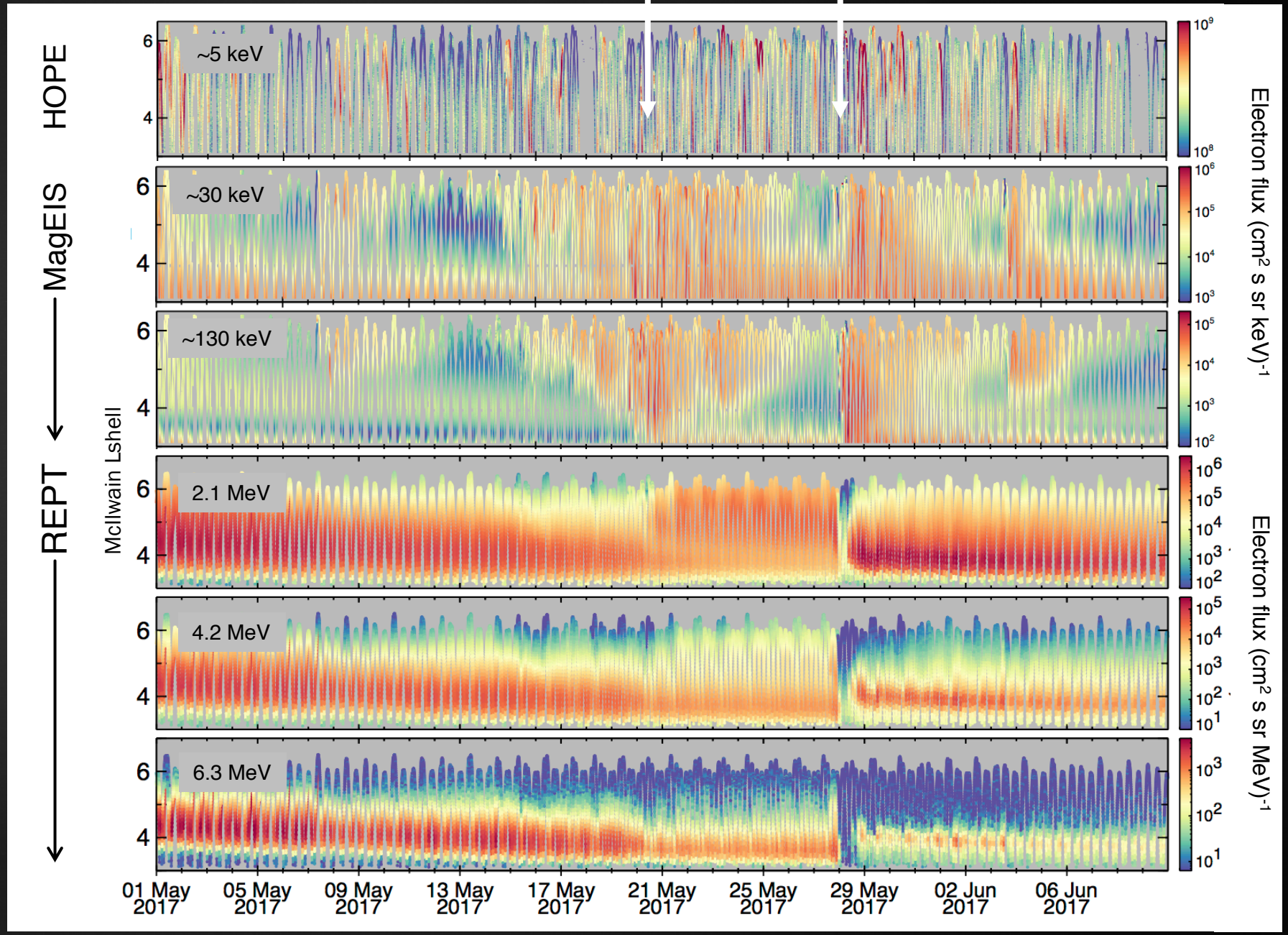
CC=0.78 for E=1.8 MeV, L=5.0	(*lag time = 9 hours*)
CC=0.80 for E=2.1 MeV, L=5.0	(*lag time = 19.5 hours*)
CC=0.83 for E=2.6 MeV, L=5.0	(*lag time = 20.5 hours*)
CC=0.82 for E=3.6 MeV, L=5.0	(*lag time = 20.8 hours*)

Case study II: May storms of 2017

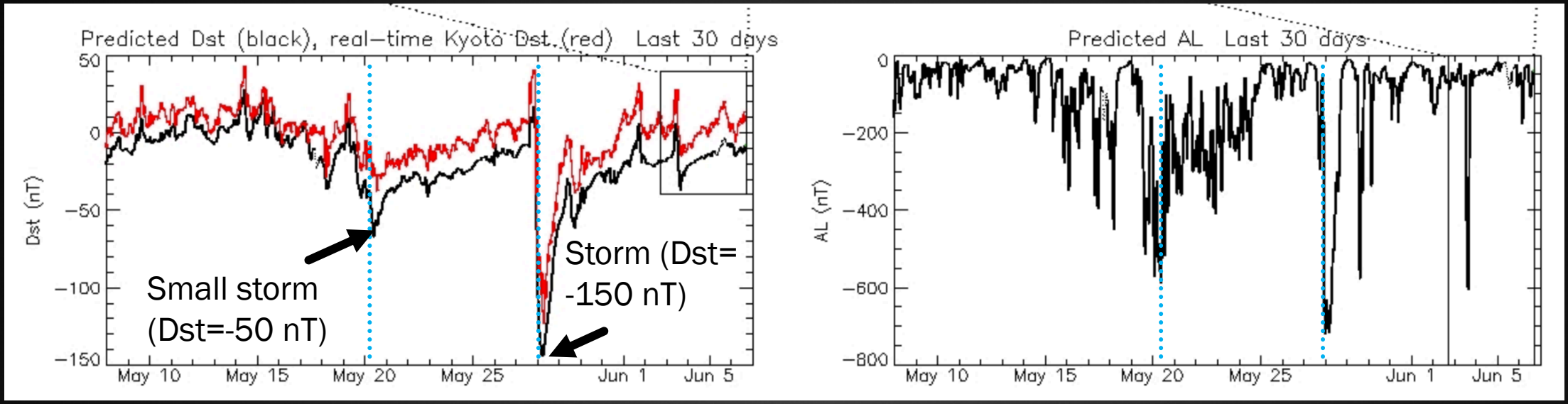
Small storm on May 20, larger storm on May 28

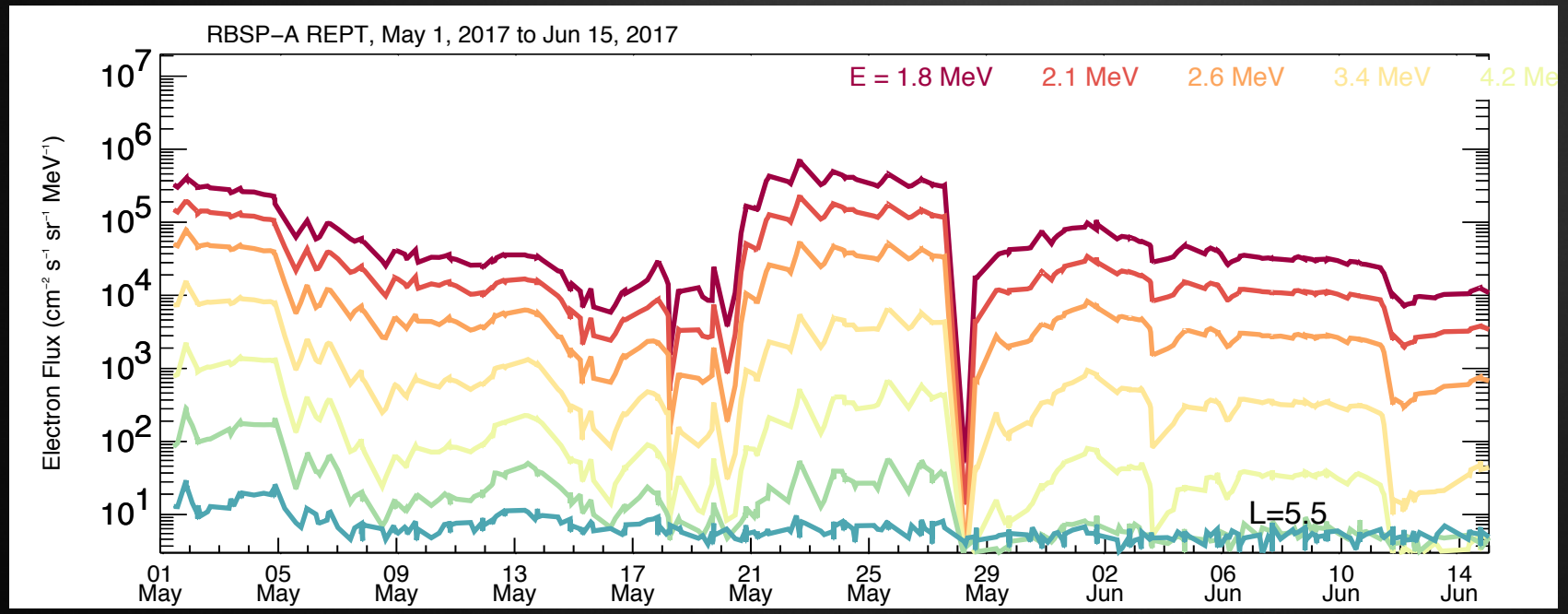
More source energy AND seed energy electrons during the first storm

Larger total RBE during first storm; differences in acceleration location



Case study II: May storms of 2017





Small storm produced more enhancement than second storm, for all ultra-relativistic energies

Case study II: May storms of 2017

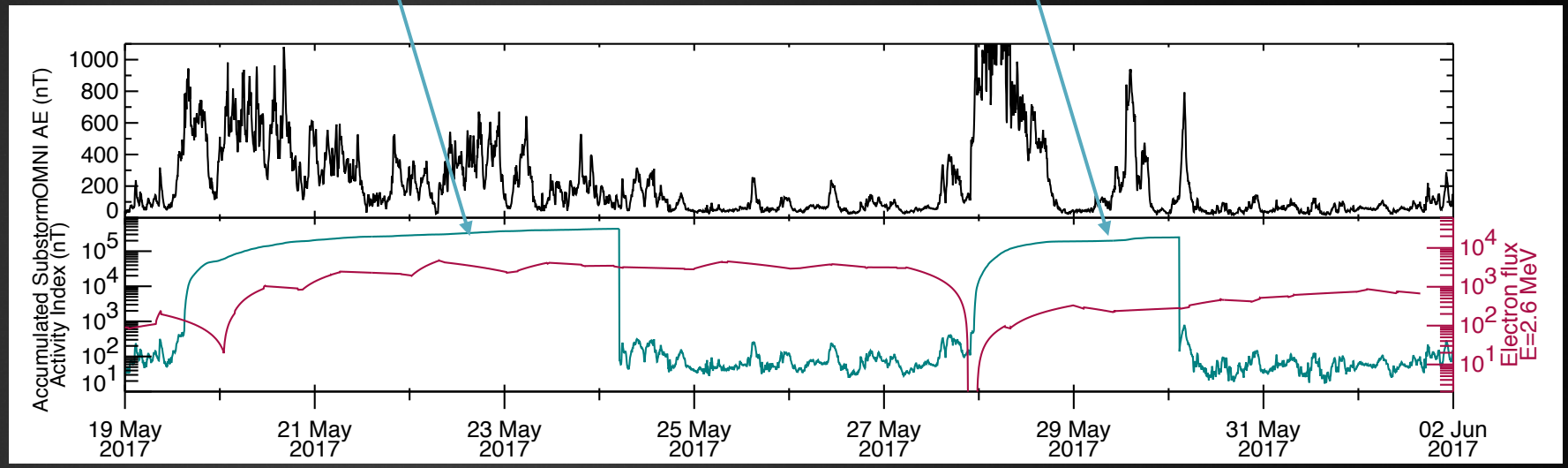
First interval was a much smaller storm but produced a larger RBE

Second interval was a larger storm but produced a smaller RBE

An index like ASA can be used to understand the differences and to quantify acceleration timescales

Maximum
ASA=435,854

Maximum
ASA =249,302



First interval had a maximum CC of 0.91 at lag of ~0.9 days

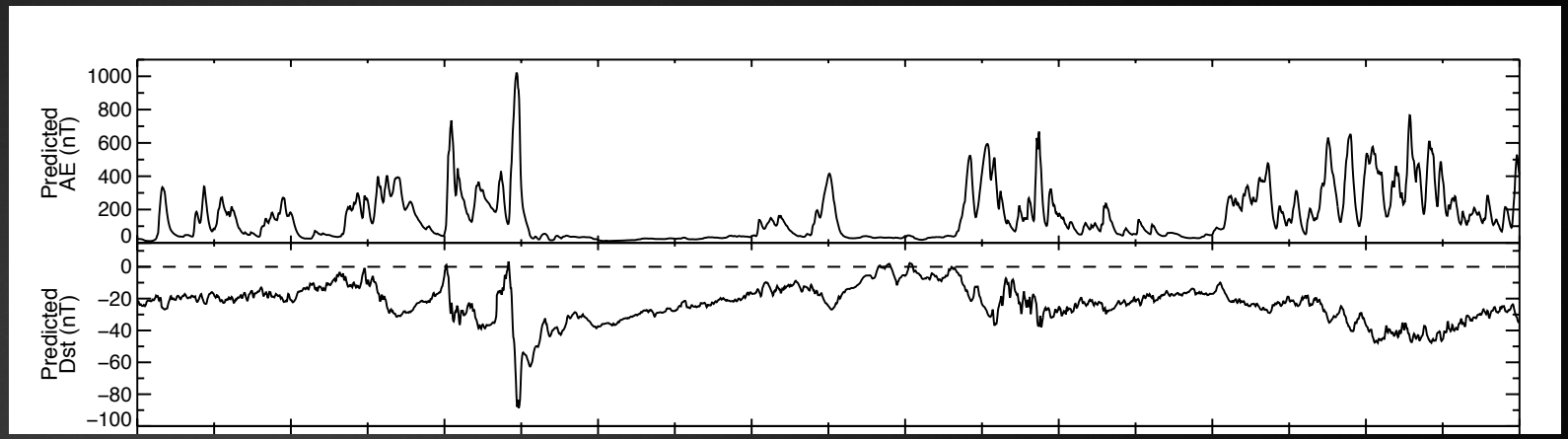
Second interval had a maximum CC of 0.76 at lag of ~0.5 days

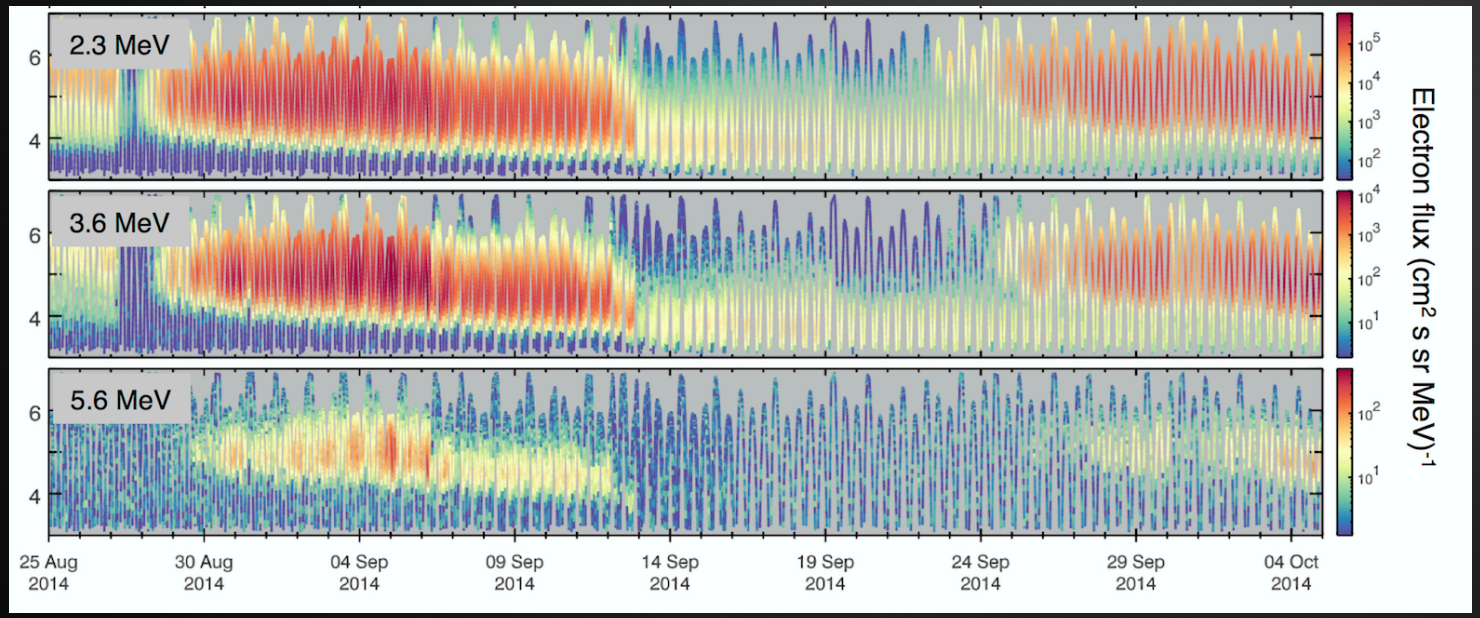
We have accumulated a table of RBEs, with correlation to ASA index for different energies and lag times at maximum CC.

Back to Sept 2014 storm with no RBE

Clear lack of AE activity in the Sept 2014 storm

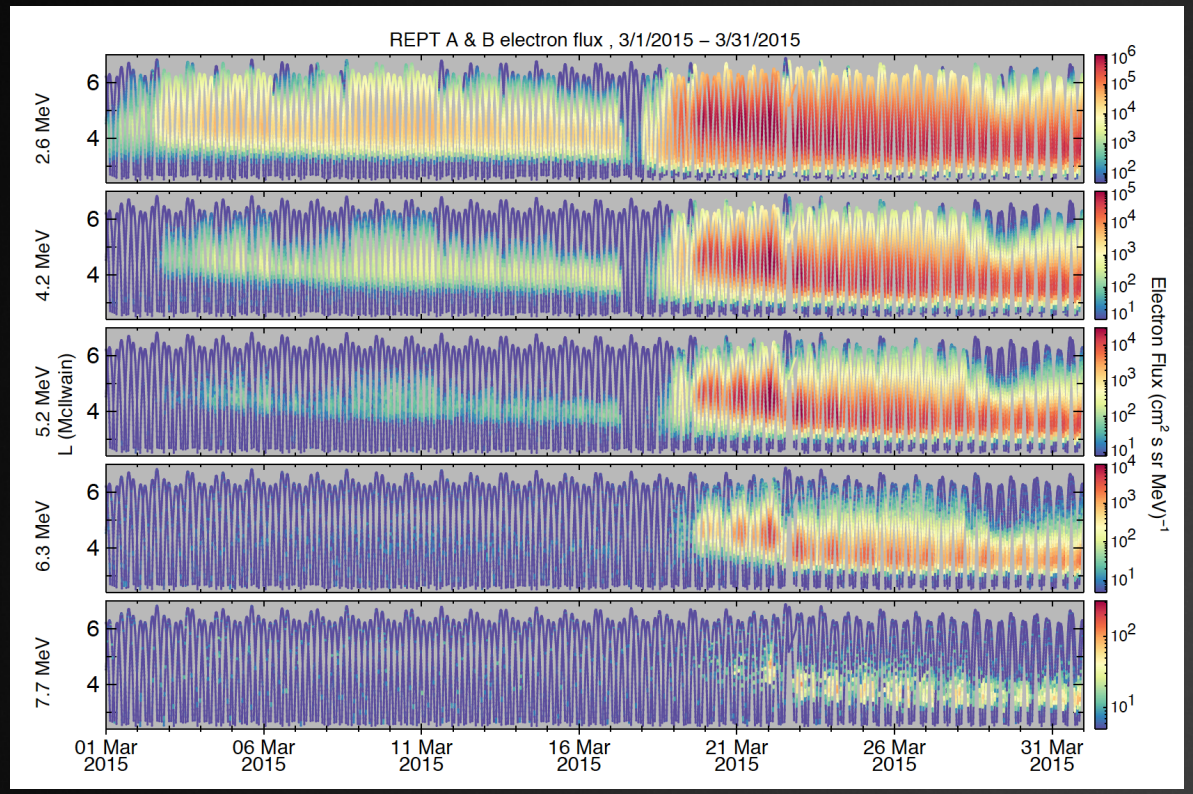
ASA index can also say that there will NOT be a relativistic radiation belt enhancement





Is this useful at all?

ULF perspective: March 17, 2015

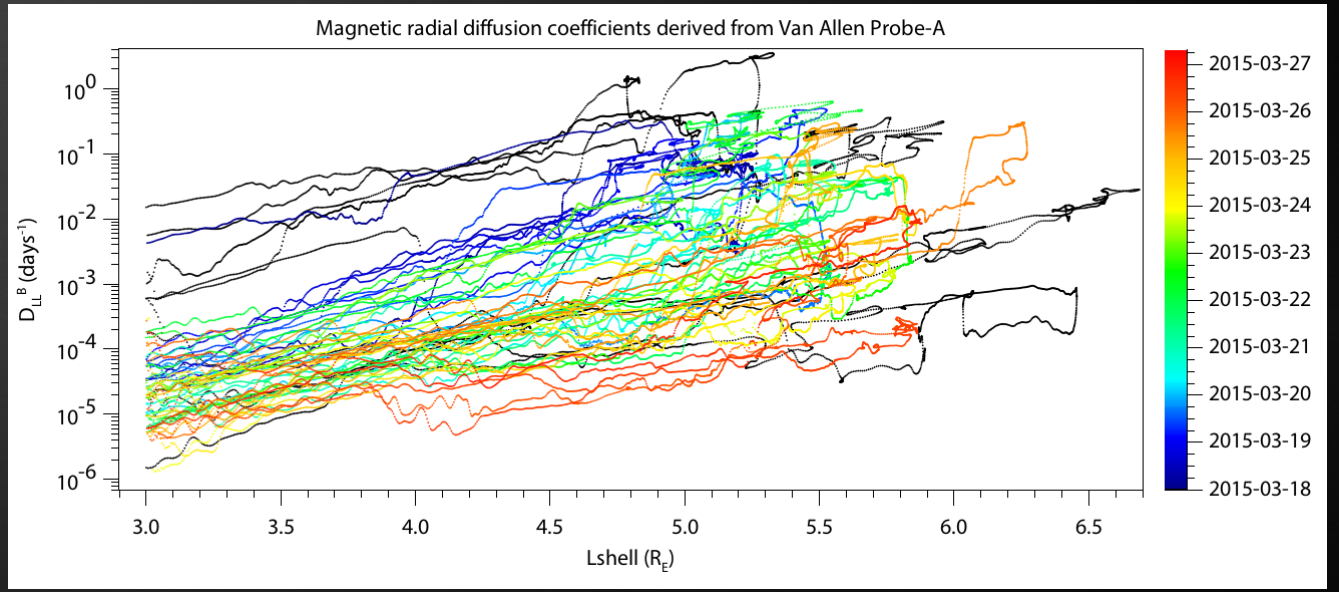


Fast diffusion of ultra-relativistic electrons following the March 17, 2015 storm event

Acceleration up to >7.7 MeV due primarily or entirely to ULF-driven inward radial diffusion; VLF waves very weak or absent in the days after storm commencement

D_{LL}^{B} derived from in situ wave measurements show the range of diffusion coefficient values during the event; much higher at times than statistical values

Diffusion rates are highly event-specific



Jaynes+ 2018 (preprint available)

Summary

- A new Accumulated Substorm Activity (ASA) index correlates well with relativistic radiation belt enhancements (RBEs)
- This serves to further connect the processes of substorm activity with the energization of Earth's radiation belts
  - (Although it does not necessarily favor either VLF- or ULF-driven processes)
- Substorm activity is a key component to the forecasting of radiation belt enhancements and should be considered strongly when creating new models or performing correlation analysis on any RB data sets